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A v.h.f. multipath simulator

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A V.H.F. MULTIPATH SIMULATOR

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Summary

A description is given of a v.h.f. multipath simulator intended for use in laboratory comparisons between different v.h.f. sound transmission systems such as standard f.m., wide-deviation f.m. and p.s.k. systems. Provision is made for generating single or multiple echoes with delays of up to 100 μs and, for some modulation systems, adjacent- or co-channel interference can also be simulated.

This equipment is a valuable tool for comparing different systems, but it must be regarded as complementing rather than replacing field trials which remain the only way of taking into account the nature and extent of the reflections which occur in practice.

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A V.H.F. MULTIPATH SIMULATOR

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1. Introduction

When investigating new transmission systems it is necessary to examine their performance under conditions of multipath propagation. Multipath propagation can cause unpleasant forms of distortion on frequency modulation (f.m.) systems or intersymbol distortion on phase-shift keyed (p.s.k.) systems. Short-range echoes can give an amplitude tilt across the pass-band or, when changing in range, a fading signal. Different methods of modulation will differ in their susceptibility to multipath interference; an equipment which can simulate a wide range of multipath propagation conditions in the laboratory is therefore a great asset when new systems are being compared.

Since the incidence of multipath propagation is not adequately known in practice, a multipath simulator cannot replace field trials but it does enable attention to be concentrated on the differences between systems in laboratory tests.

During the early investigations of v.h.f. transmissions in the UK a multipath simulator was constructed and has proved very useful. The bandwidth of this instrument was sufficient for monophonic transmissions, but was rather limited for stereo transmissions, particularly in respect of its group-delay characteristic. Future investigations may involve wide-deviation f.m. systems or phase-shift-keyed (p.s.k.) sound systems and the original simulator would no longer be suitable.

The construction of a new simulator (illustrated in Fig. 1) has therefore been undertaken. In order that the equipment will perform adequately for these new systems, it has been designed with a bandwidth of 550 kHz, tunable over the whole of Band II (87 to 105 MHz). The maximum echo delay, corresponding to a 31 km path-difference, will cover most situations. A number of echoes with different delay are available, with separate level controls. Other controls permit the phase of the echoes to be changed either manually or continuously so as to simulate aircraft reflections.

Low-frequency variations of amplitude and phase simulate the type of fading encountered by moving vehicles. Provision is also made to offset the frequency of echoes and this can be used to simulated adjacent-channel interference in some cases.

2. Brief description

At the present time it is not practical to provide a suitable series of delay lines operating directly at frequency in Band II. For this reason, the delay path in the multipath simulator operates at the low frequency of 3 MHz. This frequency was chosen to simplify the design and setting up of the delay elements, whilst avoiding the commonly used receiver i.f. frequencies or their sub-harmonics.

Figure 2 is a block diagram of the simulator. It

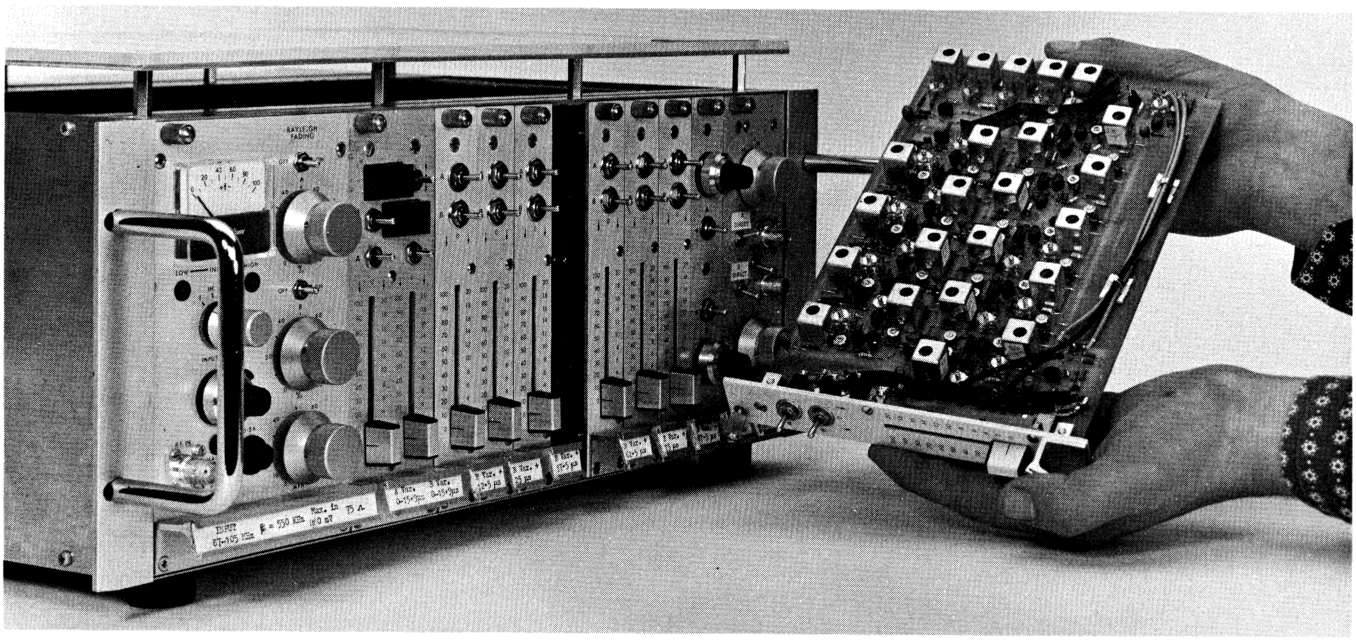

Fig. 1 - V.H.F. multipath simulator

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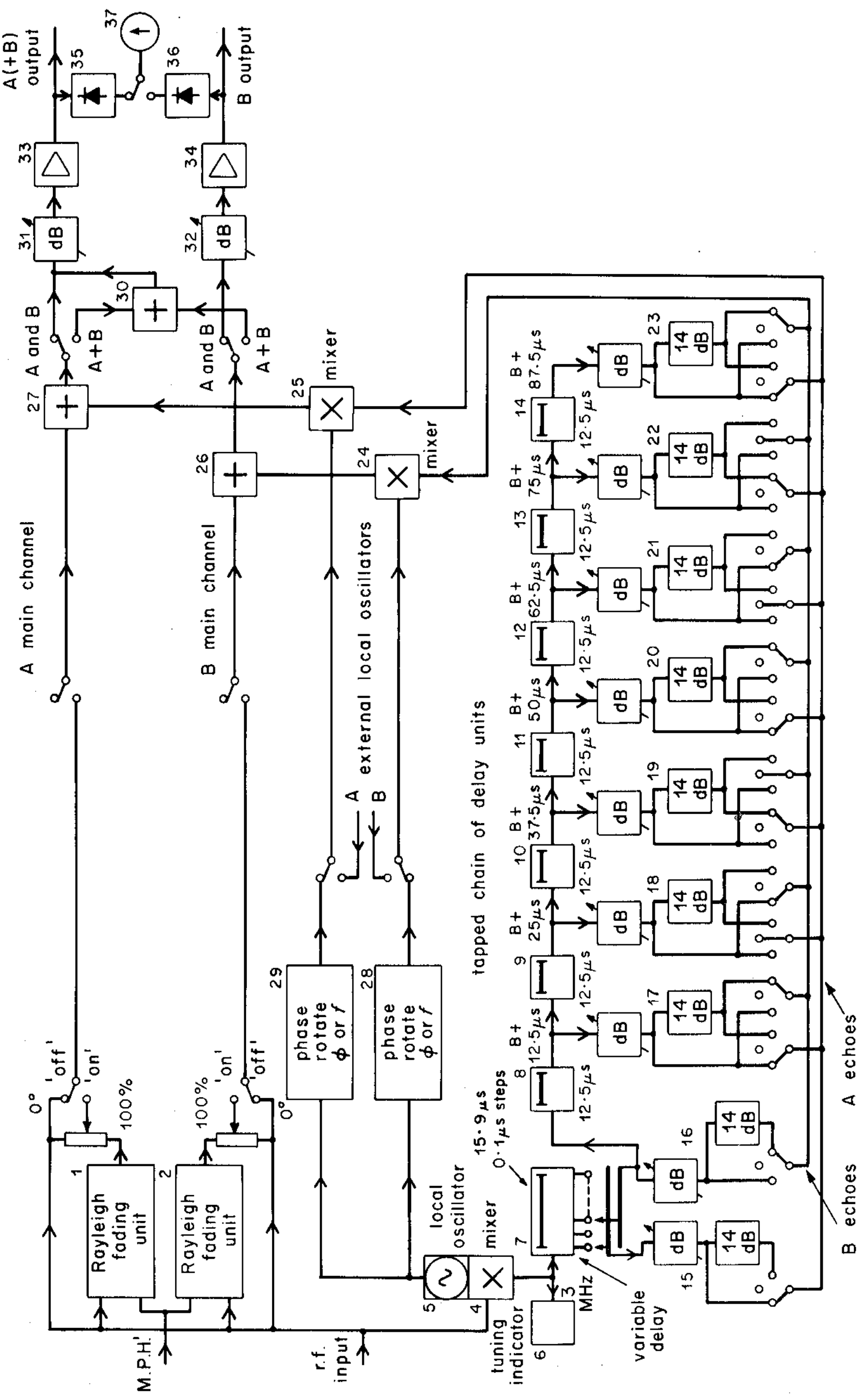

Fig. 2 - V.H.F. multipath simulator

can be seen that the input splits into three main paths. One path (with two lines) is a direct feed to the output circuits whilst a second path (also with two lines) is a feed to the Rayleigh fading units (1,2) to provide the effects of short-range fading. The third path is the feed to the frequency-changer (4,5) the output of which drives the delay units (7 to 14).

Local oscillator outputs (5) from this frequency-charger are used to re-convert the delayed signals back to the input frequency. The 3 MHz output of the frequency changer drives tuning and level indicating circuits (6) in addition to the delay lines.

The delay lines consist of a Variable Delay unit (7) with a range of 0 to 15·9 µs followed by a series of seven units (8 to 14), each with delays of 12·5 µs, thus giving a maximum overall delay of 103·4 µs. The variable delay has two independent adjustable taps whose outputs are connected respectively to the 'A' and 'B' summing lines via variable attenuators (15,16). The 'B' tap on the Variable Delay is also used to drive the following chain of fixed delays. Each of the taps along the chain of fixed delays drives a variable attenuator whose output can be connected to the 'A' and 'B' summing lines either directly or via the individual 14 dB attenuators.

The summed outputs of the delay lines drive a pair of mixers (24,25) whose outputs may be combined (26,27) with the direct-path signals to provide the r.f. output signals. The local oscillator for these mixers is normally derived from the input frequency-changer local-oscillator via phase rotators (28,29), enabling the two local oscillator feeds to be adjusted independently. Manual control of phase or an adjustable frequency offset over a range of ±200 Hz are available. These phase and frequency changes will be directly transferred to the delayed signals in the outputs. By using one control in the fixed-phase position and one on the frequency offset position the unit will simulate a combination of fixed echoes and aircraft reflections.

By switching the mixers to accept drives from external local-oscillators the delayed signals may be offset in frequency up to 1·5 MHz. For fast digital transmission systems such as p.s.k. which has short correlation times (<100 µs), this is equivalent to uncorrelated adjacent-channel interference. Since there are two independent (A, B) sets of delayed signals, a combination of adjacent-channel and reflected signals or two independent adjacent-channel signals can be simulated.

The two mixer outputs can be used independently for the A and B channels or combined (30) to form a single (A + B) output. Variable attenuators (31,32) feed the output amplifiers (33,34) with a capability of 0.7V p-p into 75 ohms.

As an alternative to the direct-path signal, it is possible to switch-in Rayleigh fading units (1,2) which vary the amplitude and phase of the signals in a manner which simulates the addition to the main signal of a large number of short-delay echoes such as are encountered by a moving vehicle in a built-up area. A control with a range of 5 to 100 m.p.h. (8 to 160 km/h) adjusts the fading rate to correspond to that of a vehicle moving with the indicated velocity in a radial direction from the transmitter.[1]

3. Specification

Max. input level	300 mV p-p across input
Input impedance	75 ohms
Frequency range	87 to 105 MHz
Pass bandwidth	550 kHz
Outputs	Either two outputs with 'A' and 'B' sets of delayed signals respectively, i.e. (Direct +A) and (Direct +B) or one output with 'A' and 'B' sets of delayed signals combined, i.e. (Direct +A+B).
Output impedance	75 ohms
Output attenuator range	40 dB
Max. output level	0.7V p-p with simple level-indicator.
Relative level of delayed signals	0 to 100%, adjustable
Variable delays	0 to 15·9 µs steps, giving two independent outputs, (A and B) each with attenuators giving 0 to 100% or 0 to 20% relative delayed-signal level.
Fixed delays (fed through one variable delay)	12·5 µs, 25 µs, 37·5 µs, 50 µs, 62·5 µs, 75 µs, 87·5 µs in a tapped chain with a variable attenuator at each step to provide either 0 to 100% or 0 to 20% relative delayed signal level.
Amplitude response	Flat to ±1 dB, over passband
Delay response	Uniform to +0.5 µs, −1 µs over passband.
Phases and frequency-offsets of delayed signals	Phases adjustable manually, with about 3600° range. Frequency-offsets of −200 Hz to −1 Hz and +1 Hz to +200 Hz (or with external oscillators ±1½ MHz). A and B sets of delayed signals independent.

Unwanted signal breakthrough	−60 dB rel. wanted signal
Local-oscillator breakthrough	−10 dB rel. max. output
Second-channel (−6 MHz) breakthrough	−20 dB rel. wanted signal
Other unwanted signal components	−40 dB rel. wanted signal (for outputs 300 mV p-p)
Crosstalk between A and B channels	−40 dB

Simulated Rayleigh fading effect available independently on both A and B direct signals, with the ratio of direct carrier to fading component infinitely variable. In addition the fading effect should be adjustable to correspond to vehicle speeds in the range 5 to 100 m.p.h. (8 to 160 km/h) at v.h.f. (Band II).

4. Detailed description

4.1. Input and Rayleigh fading unit

The r.f. input to the equipment is split by a resistive splitter into the direct signal paths and the input to the frequency-changer. This latter sub-unit is a slightly modified Band II receiver tuner unit. The modifications consist of changing the i.f. frequency to 3 MHz and bringing out a feed from the local-oscillator to supply the phase-rotators. The maximum input level to the equipment is set by the overload point of this tuner. The 3 MHz output feeds directly into the variable delay unit and via an amplifier to tuning and level indicators.

To simulate the fading of signals receiving in a moving vehicle, a Rayleigh distribution appears to have statistical properties close to those required. It has been shown by Arredondo et al[1] that this simulation can be made by using the outputs from a pair of Gaussian noise sources. These noise signals are passed through shaping filters and a Rayleigh distribution is obtained by using the two noise outputs to control the amplitudes of quadrature components of the r.f. signal. The cut-off frequency of the shaping filters is automatically varied to suit the vehicle speed.

The system adopted in this equipment for synthesising a Rayleigh distribution uses the same principle. A clocking oscillator, whose frequency is variable from about 3·5 kHz to 70 kHz, is used to control the timing of the whole operation. The oscillator drives, through a divider, a pseudo-random-sequence generator that provides a maximum-length pseudo-random binary sequence. This waveform is then passed through a clocked transversal-filter, followed by a simple low-pass filter. Four such uncorrelated "random noise" waveforms are produced in this way. Two of these are required for the generation of each Rayleigh fading output signal.

The frequencies involved are relatively low and it is possible to generate the four random noise waveforms in time-division multiplex.

After low-pass filtering, the two noise waveforms are passed to quadrature modulators[2] whose summed output forms the Rayleigh fading waveform.

mmmThe whole operation described above takes place as a clocked sequence. Thus, at a high oscillator-frequency (corresponding to a high vehicle-speed) the transversal filter has a proportionally high cut-off frequency. The shape of the fading spectrum is thereby preserved at all oscillator frequencies while the frequency scale depends upon the vehicle speed being simulated.

4.2. Variable-delay unit

Fig. 3 is a block diagram of the variable-delay unit. The 3-MHz input signal passes through a tapped chain of seven, 3-section, 2-μs delay sub-units. Fig. 4 is a circuit diagram of a pair of these sections. By inverting the d.c. polarity of alternate stages they are directly biased by the previous stage and so eliminate any special bias component except that from the first stage. The individual stages in each group of three are stagger-tuned so as to maintain a flat group-delay response over the 550 kHz bandwidth of the equipment. The design of the individual sections was based on that of an earlier delay equaliser described by Harvey;[3] in the present case, however, a much simpler bias circuit was used and, due to the lower operating frequency, there was no need for loss compensation.

The taps at the junctions of the 2 μs delay sub-units are selected by two electronic switches (8,9) which in turn feed 0·4 μs delay lines, tapped at 0·1 μs intervals (12,13). Taps are electronically selected and buffered before driving further selectable delays of 0·5 μs (20,21) and 1 μs (26,27); output buffers drive output attenuators (31,32) which feed the A and B summing lines. These attenuators consist of a continuously variable unit and a switched attenuator giving ranges of delayed-signal level from 0 to 100% and 0 to 20%, relative to the direct signal. The final 'B' delay also drives a buffer amplifier whose output signal feeds the following chain of 12·5 μs delay units.

It can be seen that a suitable selection of the delays by the electronic switches can give any delay from 0 to 15·9 μs in steps of 0·1 μs. This selection is controlled by reversible divide-by-160 counters. The two operative delays are indicated on the front panel by l.e.d. numerical displays driven by the counters.

4.3. 12·5 μs delay units

There are seven identical delay units each giving 12½ μs delay. At the input of each of these units there is a five-section Tchebychef bandpass filter. These filters, with a 0·1 dB amplitude ripple and a bandwidth of 560 kHz, define the system bandwidth. They make a large contribution (3½ μs) to the unit delay at the band edges and an appreciable delay (1·8 μs) at midband. The filter in each

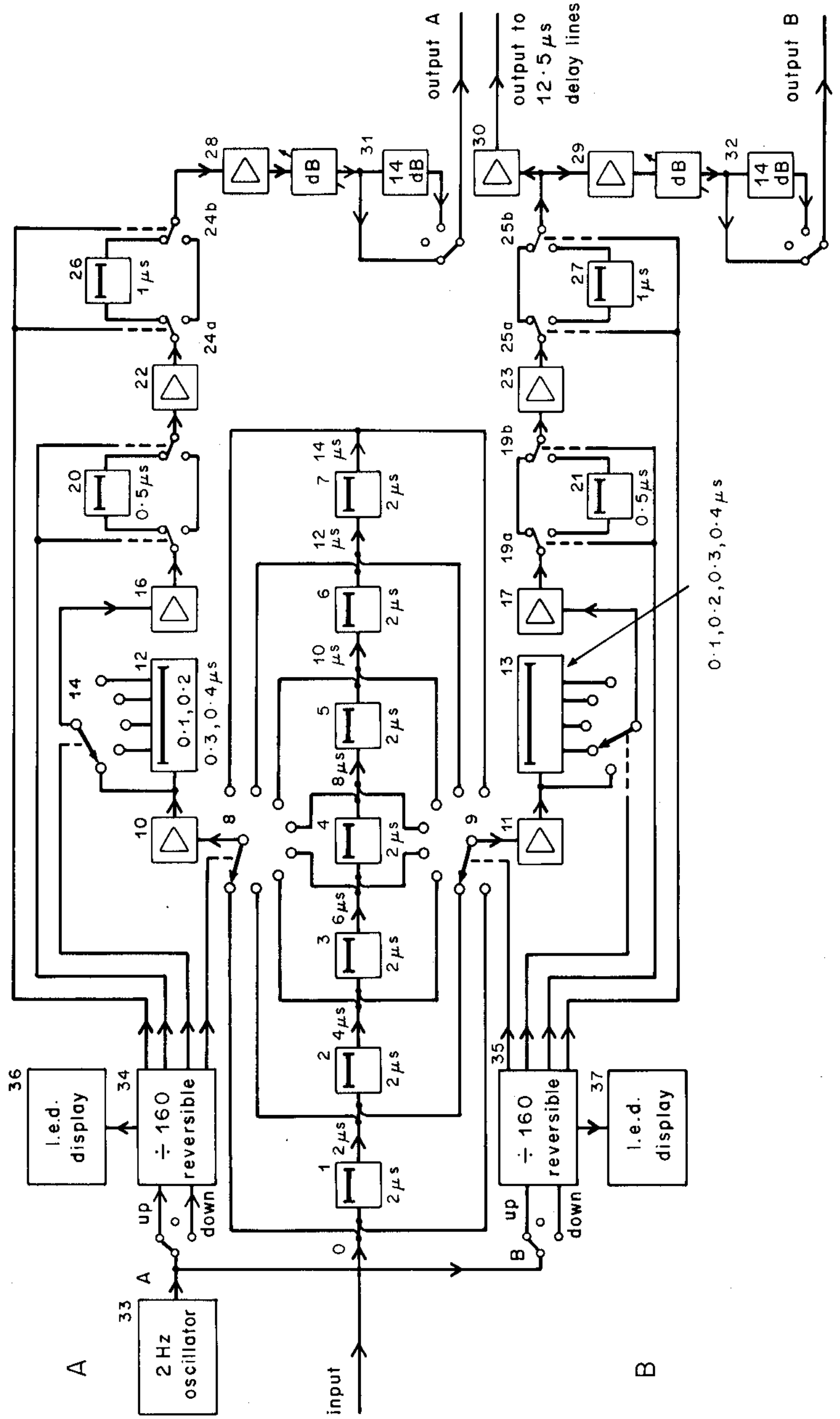

Fig. 3 - Variable delay unit

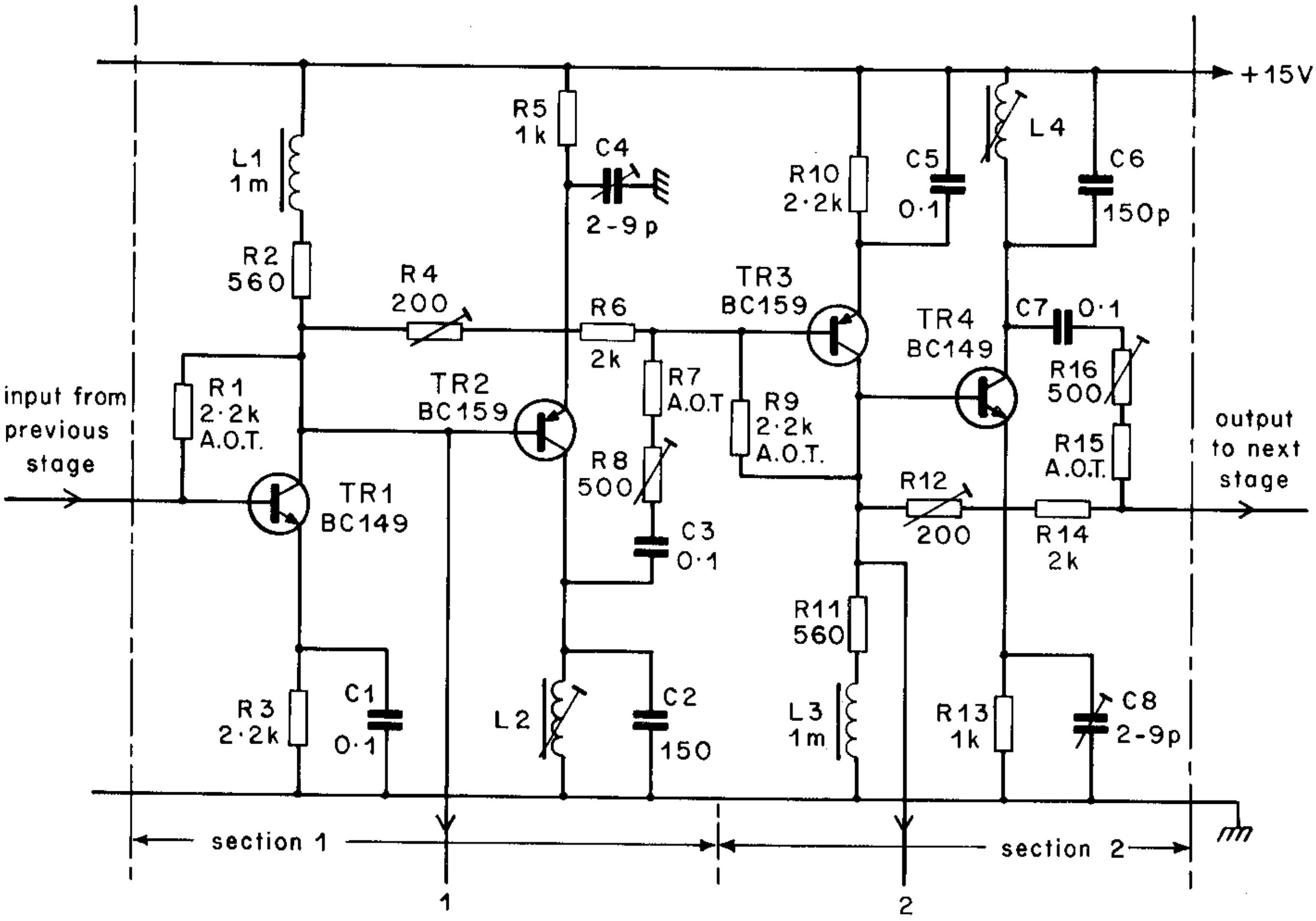

Fig. 4 - Delay stages

unit is followed by 18 sections of active delays similar to those used in the variable delay unit already described in Section 4.2.

A buffer amplifier next drives the following 12·5 μs delay unit and a variable attenuator. This attenuator in turn feeds two output amplifiers with switched 14 dB attenuators in their outputs. Finally, the outputs from these switches feed the 'A' and 'B' summing lines.

4.4. Phase-rotators

Fig. 5 is a block diagram of one of the two phase-rotators. This unit changes the phase of the local-oscillator drive to the output mixer, thus changing the phase of the delayed signal in the output. A quadrature modulator unit, identical to that used in the Rayleigh fading unit, provides the necessary phase-shift.

The 'A' and 'B' phase-rotators are identical. Each pair of quadrature-modulators requires drive-voltages that are proportional to the sine and cosine of the required phase-shift angle. For frequency-offsets these values will be changing continuously.

The method of generating the required drive-voltages shown in Fig. 5, is to frequency-change (5) the quadrature outputs of an auxilliary fixed-frequency 20-kHz oscillator (1). The oscillator in the phase-locked loop (4) is free-running and variable in frequency when small frequency offsets are required or phase-locked to the fixed oscillator when fixed phase-differences are required. The phase-locked loop operates at one-sixteenth (2) of the oscillator frequency. A variable electronic delay (3) is included in the loop circuit and enables the phase of the oscillator (and hence the phase of the output signal) to be rotated through 3600°.

4.5. Output unit

In the output unit, for which Fig. 6 is a block diagram, each group of eight delayed signals is summed by an operational amplifier. The combined delayed signal is then mixed with the appropriate local-oscillator frequency to regain the Band II input signal frequency. The mixers (3,4) are double-balanced integrated-circuit mixers, with a pre-set control to minimise local-oscillator breakthrough. A single-circuit varactor-tuned filter (not shown) gives some reduction of the second-channel component in the output signal, but this filter is designed to be wide-band (so as to permit the use of offset local-oscillators for the simulation of adjacent-channel interference) and care may

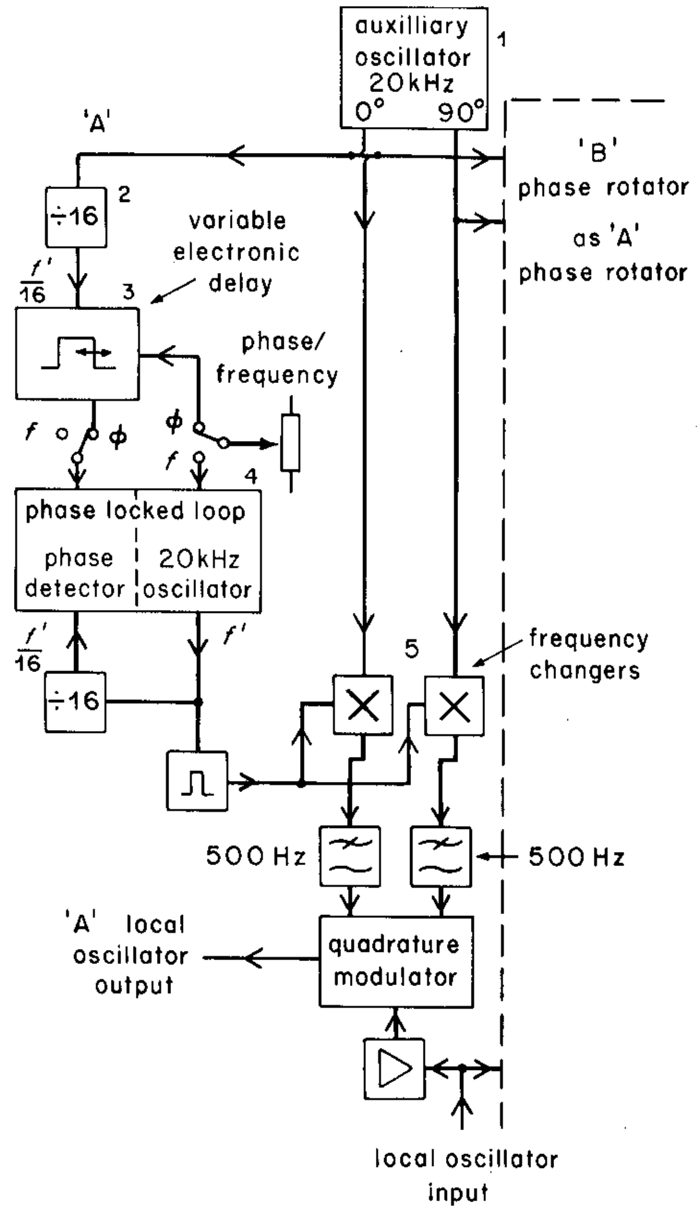

Fig. 5 - Phase rotator

be needed under some conditions of operation.

The outputs from these mixers are added to the direct-path signals in resistive networks (5,6), the combined signals from which can be used either separately or further combined to form a single output. When the signals are added to give a single output, the 'B' direct path is broken.

The two combined signals pass through variable attenuators before being amplified in power amplifiers. These amplifiers will deliver a maximum of 0.7V p-p into a 75 ohm load. Diodes are used to provide drives for the output voltmeter.

If the local oscillator that is used to frequency-change the delayed signals back to v.h.f. is removed and an external local-oscillator feed is substituted, then one or both sets of echoes (A, B) can be offset in frequency from the direct signal by up to 1·5 MHz. If long-delay echoes are used and the input signal is a fast digitally modulated signal, then the correlation between the main and offset signals will be small and the offset signal can be treated as an adjacent-channel interfering signal. In the case of f.m. radio signals the correlation may not be sufficiently low for this technique to be applicable; this will depend upon the test-signal modulation employed.

5. System parameters

The performance of the multipath simulator meets the specification given in Section 3. Plots of the amplitude and delay characteristics at maximum delay through the system are shown in Fig. 7. It can be seen that for this maximum delay of 103·4 μs the amplitude variations across the 550 kHz band are less than ±1 dB whilst the group delay variations are within the limits of +0·3 and −0·8 μs. The errors reduce as the total delay is reduced. For less exacting requirements, the useful bandwidth extends to 640 kHz, where the amplitude characteristic falls off sharply.

The principal unwanted output components occur at harmonics of the intermediate frequency of 3 MHz. These unwanted terms are unlikely to cause any problem when using receiving equipment employing standard i.f. frequencies.

6. Conclusions

The simulator described in this report is suitable for most laboratory investigations into multipath propagation for v.h.f. sound systems both analogue and digital. Facilities are provided for obtaining multiple delayed signals, with delays up to 103·4 μs, over a 550 kHz bandwidth anywhere in the range 87 to 105 MHz. The relative phases of the delayed signals can be varied either manually or continuously at frequencies up to ±200 Hz. Provision is also made for low-frequency amplitude and phase variations to simulate mobile operation. The delayed signals can be split into two separate paths for dual-diversity reception, or frequency-offsetting to simulate adjacent-channel operation in fast, digitally modulated systems.

With the range of facilities provided, this simulator should prove to be very useful in the laboratory investigation of the performance of new v.h.f. sound transmission systems. However, this equipment must be regarded as complementing rather than replacing proper field trials since laboratory tests can only be meaningful if they are based upon practical multipath conditions.

7. References

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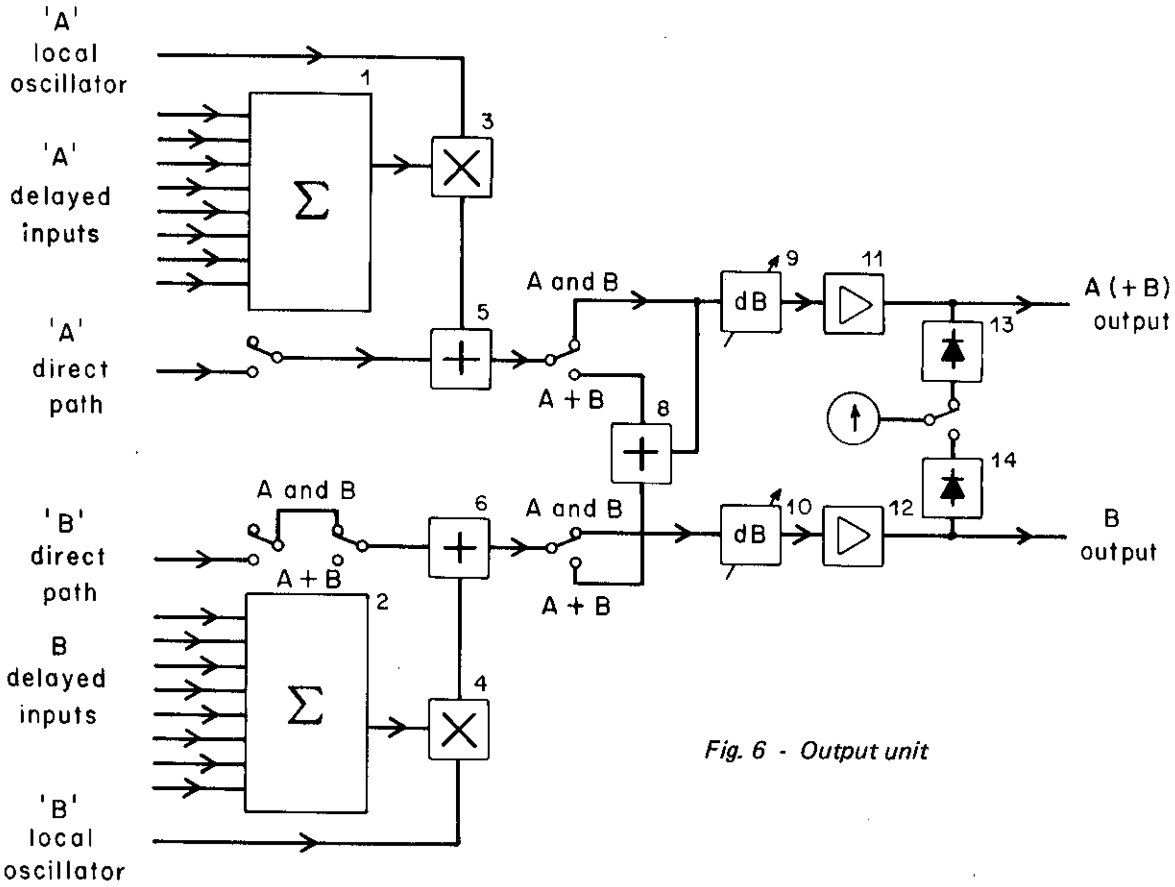

Fig. 6 - Output unit

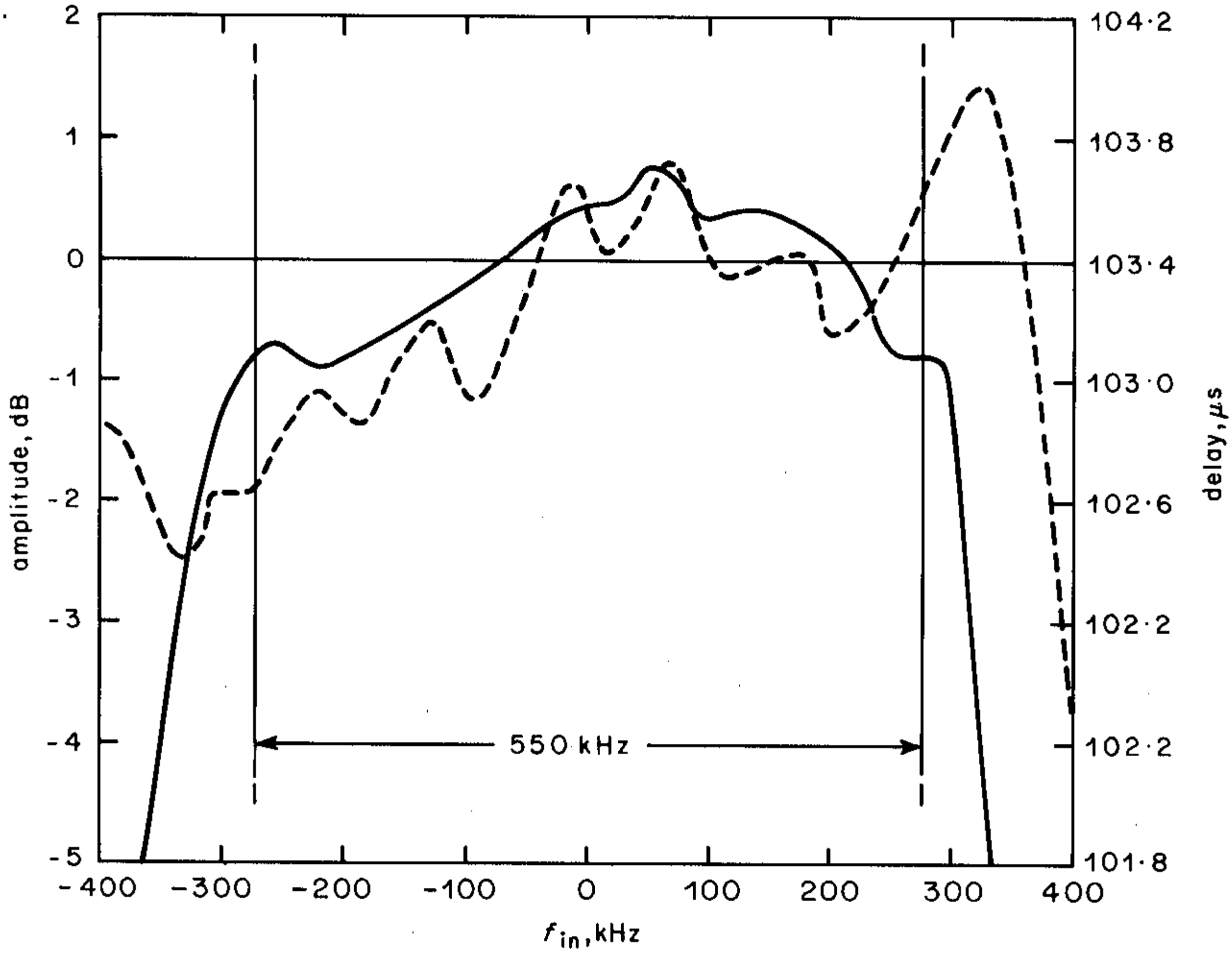

Fig. 7 - Amplitude and phase characteristics at max. delay

——— amplitude — — — delay

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